

MEASURING TRANSFER OF BIOLOGICAL KNOWLEDGE TO CLINICAL
PROBLEM SOLVING IN THE EDUCATION OF DENTISTS

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1989

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ACKNOWLEDGEMENTS

I wish to express appreciation to the members of my graduate advisory committee: Dr. James W. Hensel, chairman, Dr. Richard S. Mackenzie, and Dr. James L. Wattenbarger for their encouragement and support during my graduate studies. I particularly wish to thank my mentor, Dr. Richard S. Mackenzie, for providing the opportunities to participate in many experiences in dental education and research, and for his guidance in applying my training to the practice of dental education and clinical research.

Special thanks are extended to my immediate family, Donna Lou, Laura, and Amy; to my parents, Harold and Helen Martin; and to my extended family, especially Len and Joan Wilkins, for the interest, support, and encouragement they have given me throughout my professional education.

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Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
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MAY 1989

Chairman: James W. Hensel
Major Department: Educational Leadership

The purpose of this study was to describe the development, validation, and experimental application of a measure of transfer of biological knowledge (the BioTrans test) to clinical problem solving in dentistry. Validity and reliability of the BioTrans test were evaluated by investigating the relationships between scores on the BioTrans test instrument and scores on (a) the Functional Job Knowledge Test (FJKT), a context-sensitive measure of cognitive structure; (b) the Word Association Test (WAT), a context-free measure of cognitive structure; (c) the final class rank of examinees; and (d) a separate administration of the BioTrans test. Sensitivity of the BioTrans instrument for detecting effects of experimental treatment in learning biological concepts was also evaluated.

Test data for 65 senior dental students at the University of Florida College of Dentistry were collected and analyzed, utilizing correlational and repeated measures analysis of variance (ANOVA) designs. Evidence for criterion-related construct validity was provided by a significant positive correlation ($p < .05$) between BioTrans test scores and FJKT scores. Evidence for the stability type of reliability was furnished by a positive significant correlation ($p < .05$) between successive administrations of the BioTrans test using different patient management problems. Analysis of the effects of experimental treatment, by repeated measures ANOVA, furnished support for the construct validity of the BioTrans instrument and for its sensitivity in detecting such effects. Meaningful overlearning was found to produce greater transfer of biological concepts ($p < .05$) to the process of clinical problem solving than either simple overlearning or experiential learning. Simple overlearning and experiential learning did not differ in degree of transfer of biological concepts. No evidence was found for criterion-related concurrent validity using the WAT, nor for validity in predicting final class rank.

Findings suggest that the BioTrans test instrument can be used with appropriate patient management problems to measure transfer of biological knowledge to dental clinical problem solving. The BioTrans instrument can be helpful in

a detailed evaluation of dental student performance and in
evaluation of teaching program effectiveness.

CHAPTER I
INTRODUCTION TO THE PROBLEM

"Many people would sooner die than think.
In fact they do." -- Bertrand Russell

In recent years, instruction in thinking and problem solving has received a considerable amount of attention in the educational literature and in the public press. At least two phenomena appear to be at work prompting this recent attention. First, rapid changes occurring in today's culture require skills in thinking and problem solving to cope with the accelerating appearances of new problems and new technology (Nickerson, 1984; Simon, 1980; Tuma & Reif, 1980). Policy decisions made by public and corporate officials in such affairs as strategic defense or nuclear energy safety, for example, have been subjected to the cold scrutiny of the press. Often, the conclusions drawn by journalists suggest that skills in critical thinking and problem solving are not common attributes of these public and corporate officials (Young, 1980). These journalistic observations sometimes imply that public and higher education have failed to provide their graduates with adequate development of critical thinking and problem-solving skills before they assume positions of responsibility. Second, recent evaluations of student achievement confirm the belief that development of

effective thinking and problem-solving abilities is not a product of our educational programs (Association of American Colleges [AAC], 1985; Halpern, 1984; National Assessment of Educational Progress [NAEP], 1983; Norris, 1985; Simon, 1980). Much of the recent research in problem solving has been directed toward understanding and resolving this perplexing situation.

This introductory section provides an overview of recent research in problem solving and its contribution to the understanding of related issues, which leads to the focal problem for this study, measuring the use of biological knowledge in the process of clinical problem solving in dentistry. The overview of problem-solving issues will have the following organization:

1. Historical and present concerns for developing problem-solving skills in higher education.
2. The controversy over transfer of problem-solving skills among content-specific domains.
3. Medical and dental clinical problem solving.
4. Transfer of biological knowledge in dental clinical problem solving.
5. Measuring clinical performance and transfer of training in clinical problem solving.

Some investigators equate the terms critical thinking, decision making, reasoning ability, and problem solving (Ettinger, 1984; Holyoak, 1984; McCaulley, 1987; Woods, 1987); others distinguish among them (Elstein, Shulman, &

Sprafka, 1978; Halpern, 1984; Paul, 1987; Swartz, 1987; Young, 1980). The ensuing discussion uses the terms critical thinking, reasoning, decision making, and problem solving interchangeably.

Historically, the search for effective teaching of general problem solving has had an extended, if inglorious, past. The ancient Greeks relied upon mathematics to make a person "quick to learn, retentive, and shrewd" (Mann, 1979, p. 13). Similarly, as Europe emerged from the dark ages into the age of enlightenment, philosophers and scientists, such as Sir Francis Bacon and John Locke, advocated the mental discipline provided by the study of mathematics or Latin to develop abilities in thinking and learning. By the nineteenth century, American higher education had accepted the need for a liberal arts education based on the trivium and quadrivium of the ancient Romans (Levine, 1978). Such a curriculum was thought to instill competency in critical thinking and judgment, deemed essential for the educated elite of the nation. The curriculum philosophies of the early American institutions of higher education were epitomized in the Yale Report of 1828, which stated that the purpose of a college curriculum was to provide the "discipline and furniture of the mind" (Levine, 1978, p. 502). The foregoing excerpts serve to illustrate the historical concern for what is now called "cognitive process training" by cognitive scientists (Bransford, Arbitman-Smith, Stein, & Vye, 1985).

In the Yale Report of 1828, "discipline" was a reference to the development of the mental faculties or thinking abilities; "furniture" indicated acquired knowledge. The dichotomy expressed in the phrase, discipline and furniture of the mind, suggests another dichotomy in the realm of general problem solving; it is frequently expressed in terms of process and content. In cognitive science, process is a term used to describe the thinking activities (cognition) which are directed toward some end, such as solving a problem or making a judgment or decision. Content is the knowledge or information base from which appropriate concepts are drawn to carry out a thinking activity, for example, deciding on a course of action (de Sanchez, 1987; Mann, 1979). Researchers have long held the theory that both process and content are requirements for effective, purposive use of knowledge. This theory came under severe attack by E. L. Thorndike in the early twentieth century, when he concluded from his work that transfer of thinking skills (process) between disciplines was minimal (Glaser, 1984). One effect of Thorndike's work was to touch off what Mann (1979) has described as "transfer-of-training wars" (p. 371). Some related skirmishes of these wars occasionally surface in the current literature (e.g., Harasym et al., 1979).

There is not full agreement among problem-solving investigators whether or not there are general critical thinking skills which are transferable among a variety of content-specific domains (Glaser, 1984; Halpern, 1987;

Resnick, 1983). In a recent critical review of the teaching of thinking and problem solving, Bransford and colleagues concluded that problem-solving skill requires use of general problem-solving strategies combined with access to a broad knowledge base in the domain of interest (Bransford, Sherwood, Vye, & Rieser, 1986). This theory became prominent in recent years as cognitive scientists began to recognize the importance of specific knowledge in artificial intelligence applications (Waldrop, 1984), as well as in education (Glaser, 1984). Many of the studies which support this conclusion involved comparisons of expert and novice performance in problem solving within specific disciplines, such as engineering, physics, mathematics, social sciences and clinical medicine. These studies also lend credence to the duality theory (of process and content) in another sense. Learning a skill requires teaching the components of the skill and providing guided practice in their use (Mackenzie, 1986). Components of the skill of problem solving can be considered to involve the process dimension, whereas guided practice takes place making use of the body of knowledge within a content-specific domain.

There is debate about what skills are involved in critical thinking. Halpern (1987) has provided a useful definition of critical thinking as "systematic, goal-directed thinking that includes evaluation of the assumptions, processes, and outcome in making a decision, solving a problem, or formulating inferences from information given"

(p. 75). Also, models of the general problem-solving process have been formulated by several investigators (Bransford & Stein, 1984; Dressel & Mayhew, 1954; Polya, 1971; Rubinstein, 1975; Simon, 1979; Whimbey & Lochhead, 1982; Woods, 1987). Many of them have common features which describe the generic strategies employed in problem solving, and which can be summarized by the following categories of activity:

1. Recognizing or identifying a problem.
2. Gathering data about the problem and restating it in the formal terminology of the domain.
3. Forming causal hypotheses and planning for problem solving by applying chosen principles.
4. Testing the hypotheses by carrying out the plan.
5. Evaluating the outcome of the plan.

Here again, much of the current knowledge of the process of problem solving has been gained in studies of expert problem solving in various disciplines. Discovery of the methods (process) by which experts use their broad knowledge base (content) strengthens the argument that general problem-solving skills are teachable and can be transferred from one domain to another (Adler, 1987; Perkins & Salomon, 1987; Swartz, 1987; Yinger, 1980). The problem of transfer of skill training also was addressed by Bransford and colleagues (1986) in the context of access to concepts and procedural knowledge stored in memory. Access to relevant memory stores depends upon the complexity of memory organization and upon the inclusion of application cues learned with this

knowledge. Lack of appropriate cues results in knowledge that is relatively "inert", as described by Alfred North Whitehead (1929). Thus, skill-oriented knowledge as well as information-oriented knowledge must be made accessible for effective use in new situations through proper teaching and learning strategies which include cues about applications of the knowledge.

One field in which a great deal of attention is paid to problem solving is clinical practice in the health sciences. In this field, discussion will be limited to medical and dental clinical practice.

Problem solving is the essence of clinical practice in dentistry and medicine (Boring & Nutter, 1984; Ettinger, 1984; Fischman, 1986; Neidle, 1986). In an extensive review of medical education (Association of American Medical Colleges [AAMC], 1984), the necessity of problem-solving training in clinical medicine was underscored. This report stimulated much discussion about medical education. One question arising from the discussion was, "Can clinical problem solving be taught?" The answer provided by a review of the recent research was yes, but with some qualifications, for example, if the faculty models the desired behavior carefully (Whitman & Schwenk, 1986).

The effectiveness of predoctoral medical and dental education programs in producing clinicians with problem-solving competence has been called into question (AAMC, 1984;

Boring & Nutter, 1984; Culliton, 1984; DePaola, 1986; Ettinger, 1984; Fischman, 1986; Neidle, 1986; Roth, 1986; Small, 1983; White, 1986; Whitman & Schwenk, 1986). In an effort to correct this deficiency some programs are being revised to include problem-based curricula, development of analytical skills, and training in developing problem-solving strategies (Abrahamson, 1987; Boring & Nutter, 1984; Evangelauf, 1987; McFarland, 1987). Such approaches stem from the common recognition that dental and medical students have difficulty applying basic biological science concepts when confronted with a clinical problem (AAMC, 1984; Roth, 1986). The ability to solve clinical problems rests on access to basic biological knowledge and clinical science knowledge stored in long term memory (the content aspect), and the use of cognitive skills (the process aspect) to bring that knowledge to bear on a problem (Bransford, 1979; Ettinger, 1984; Glaser, 1984; Mayer, 1977). Thus, the phenomenon of transfer of training involves both process and content knowledge. If it is accepted that problem solving is a transferable skill, then, in order to improve that skill, much guided practice is needed. One does not practice process skills in the absence of a knowledge base, but must use the knowledge base during practice.

Review of the dental education literature reveals that little has been reported concerning the actual process of clinical problem solving in dentistry (Ettinger, 1984; Kress, 1980). Mackenzie and co-workers have reported studies

(Mackenzie, 1965; Mackenzie & Bennett, 1967; Mackenzie, Hollway, Secola-Ocanto, & Marynuik, 1986; Mackenzie & Kilpatrick, 1976) which investigate utilization of biological information by groups of examinees, measured by the Functional Job Knowledge Test (FJKT). This instrument elicits the examinee's free recall of clinical incidents, and measures memory organization in the context of clinical incidents. Because the examinees are not confronted with the same clinical problem or incident, the results are usually analyzed with a group of examinees as the unit of analysis.

In view of the renewed interest in teaching clinical problem-solving skills, there needs to be an accompanying development of evaluation measures which (a) reflect current problem-solving theories, (b) can utilize simulated clinical problems, (c) place the examinee as the unit of analysis, and (d) have been tested for validity and reliability. Very recently, Norman (1987) has written about the current state of clinical performance evaluation instruments:

Certainly, a review of recent basic studies suggests that the field is dominated by methods such as short term recall of clinical data, rapid perception of visual stimuli, or "thinking aloud" around clinical problems. Rarely are the measures subjected to the conventional yardsticks of reliability and validity, therefore it is unclear how these methods could find useful application as evaluation instruments. (p. 75)

Statement of the Problem

Renewed interest in revising curricula in medical and dental schools to improve the very foundation of clinical practice will require that valid, reliable, theory-based

measures of clinical performance, including transfer of biological knowledge to clinical problem solving, be developed. Few validated instruments have been reported which directly measure this effect for individuals.

The primary purpose of this study was to develop an instrument for assessing access to and transfer of basic biological knowledge to solving clinical problems by senior dental students (designated the BioTrans test), and to test the instrument for construct and predictive validity and reliability. A second purpose of this study was to collect data using the BioTrans instrument to determine whether it will detect effects of differential treatment in an experimental study of teaching and learning interventions in the University of Florida College of Dentistry. The interventions were undertaken to improve dental students' abilities to transfer basic biological science knowledge to clinical practice.

Research Questions and Hypotheses

The research questions and their related hypotheses addressed in this study were the following:

1. Are the scores on the BioTrans assessment instrument related to scores on an existing context-sensitive measure of cognitive structure, the FJKT? This relationship was tested by examining the research hypothesis that the Pearson product-moment correlation between scores on the BioTrans test and

the FJKT is greater than zero ($H_1: r > .00$) at $\alpha = .05$, as evidence of construct validity.

2. Are scores on the BioTrans instrument related to scores on an existing context-free measure of cognitive structure, the Word Association Test (WAT)? This relationship was tested by examining the research hypothesis that the Pearson product-moment correlation between scores on the BioTrans test and the WAT is greater than zero ($H_2: r > .00$) at $\alpha = .05$, as evidence of concurrent, criterion-related validity.

3. Are scores on the BioTrans instrument related to the final class rank of the examinees? This relationship was tested by examining the research hypothesis that the Spearman rank-order correlation between scores on the BioTrans test and final class rank of examinees is greater than zero ($H_3: r > .00$) at $\alpha = .05$, as evidence of predictive criterion-related validity.

4. Are scores on the BioTrans instrument stable when examinees are tested on separate problems? This question was tested by examining the research hypothesis that the Pearson product-moment correlation between scores on the BioTrans test for two separate problems is greater than zero ($H_4: r > .00$) at $\alpha = .05$, as evidence of stability.

5. Did the results of the BioTrans test reflect the effects of differential treatment when learning biological concepts during the freshman year, further demonstrating

construct validity and test sensitivity? This question was tested by examining the null hypothesis that there are no differences in the mean number of reported biological concepts, learned by one of three different methods during examinees' freshman year, ($H_0: \mu_1 = \mu_2 = \mu_3$) evaluated at $\alpha = .05$.

In summary, the first three hypotheses were formulated to determine construct validity of the BioTrans instrument by correlational methods. The fourth hypothesis was posed to test the stability type of reliability of the instrument by a correlational method. The fifth hypothesis was formulated to determine construct validity as well as test sensitivity by examining treatment effects expected by application of theory.

Delimitations

The study was constrained in several ways. First, the examinees were a single senior class of 65 dental students at the University of Florida College of Dentistry. Second, throughout the four year dental school curriculum, all examinees experienced nearly identical training. They differed only in elective course work (representing 4% of the total program effort) and in the assignment of learning sets of biological concepts during the freshman year. Third, all testing concerned with this study was accomplished in a testing center under well controlled testing conditions. Fourth, the problems used to test clinical problem-solving

ability are unique to this college of dentistry, although similar in general format to patient problems used for testing in other dental schools. These problems are sometimes called "Patient Management Problems" or "Simulated Patient Problems." The proportion of North American dental schools using similar patient problems has not been reported.

Limitations

With respect to internal validity, this study was partially limited in controlling confounding variables because no random selection of senior students was utilized. This limitation is attenuated by the random nature of assignment of the sets of biological concepts to be learned by the three methods. In addition, this portion of the study was made statistically more powerful by having each student act as his/her own control. Each student learned one set of concepts by the control method, another set of concepts by the first experimental method, and a third set of concepts by a second experimental method. Another potential limitation is that dental student classes are quite homogeneous in pre-professional preparation, experience, and abilities. This homogeneity may result in restriction of range of variability of performance scores, potentially reducing validity and reliability coefficients (Crocker & Algina, 1986, p. 226).

Significance

The revival of concern among dental educators for developing curricula that foster problem-solving abilities in their graduates indicates a need for adequate, valid,

reliable measures to evaluate outcomes of new programs. Furthermore, such measures should be based on current theories of problem solving and transfer of knowledge. The foundation of dental practice is clinical problem solving. This professional attribute requires a well-developed understanding of biological phenomena and the skill to apply that understanding. A valid and reliable measure of knowledge transfer in problem solving will be valuable to dental educators for evaluating programs and student performance.

Assumptions

It is assumed that the senior dental students were motivated to produce a test result that is an accurate representation of their ability to use biological knowledge in clinical problem solving. This assumption is strengthened by the inclusion of the BioTrans test in the final test sequence for a required module. A passing evaluation for the module is a necessary condition for graduation.

Definition of Terms

Some of the terminology used in this study require definition for the reader to have a clear understanding of the information presented.

BioTrans test is the instrument developed in this study to measure transfer of biological knowledge to clinical problem solving in dentistry.

Cognitive Structure refers to the way in which the contents of memory are organized and interrelated. The

degree of interconnection of ideas, concepts, facts, or principles is a measure of how well they are understood.

Context refers to the background or setting in which learning takes place. Broadly interpreted, it includes stimuli both external and internal to the learner, such as understanding a future use of the information to be learned as well as affective sensations experienced by the learner.

Critical Thinking is the process of rationally deciding what to think or do. Attributes of this thinking process include systematically applying criteria, evaluating information, and utilizing reasoning and judgment. It is a skill which can be improved with practice (Mackenzie, 1986; Norris, 1985; Swartz, 1987).

Judgment is the thinking process involved in deciding between two or more alternatives. One utilizes judgment when determining if an event falls into a certain category or not.

Metacognition literally means thinking about thinking. It refers to the active statements and questions used during thinking, judging, and reasoning. These questions and statements guide one's thinking and learning activities.

A problem is an existing situation which differs from a desired situation or goal.

Problem solving is the process by which a person changes a problem to a desired goal. There are several recognized components of problem solving. These include gathering and evaluating information about the problem, formulating a plan to reach the desired goal, executing the plan, and evaluating

the outcome of the plan relative to the desired goal. In its broadest sense, problem solving involves the use of judgment, reasoning, critical thinking, and decision making.

Reasoning is the intellectual activity of using previous knowledge and new information or observations to formulate a conclusion or inference. Judgment is part of the reasoning process.

The term transfer indicates the application of previously learned knowledge or skills to a new situation. Thus, for example, transfer of biological knowledge to clinical problem solving involves the use of knowledge gained in one situation (learning from a biological science course) to understand or solve a problem in another situation (a clinical problem presented by a patient).

Summary

Acquisition of problem solving skills is an educational ideal which has recently received increased attention by administrators in higher education, including those concerned with the education of clinical health professionals. Presently, controversy exists among researchers concerning the existence of independent problem solving process skills, whether these skills can be applied to a variety of disciplines, and the role played by specific knowledge in problem solving.

Clinical problem solving is the primary function of medical and dental practitioners and is based on biological knowledge. Lately, educators in medicine and dentistry have

planned curriculum changes which are designed to improve clinical problem-solving abilities in their graduates. Reliable, valid measures are needed to evaluate both program effectiveness and individual competence in problem solving, to understand how and how well biological information is utilized in clinical practice. A research study was proposed to design and evaluate one type of measure, namely, a test of transfer of biological knowledge to clinical problem solving by dentists.

CHAPTER II REVIEW OF LITERATURE

Introduction

The purposes of this study were twofold. The first was the construction and validation of an instrument for measuring transfer of basic biological knowledge to specific clinical problem-solving exercises by dental students. The second was to determine whether the instrument is sufficiently sensitive to detect differential treatment effects among senior dental students on acquisition of basic biological concepts occurring during their freshman year. In order to construct and test such an instrument, a cogent review of the literature is necessary in several subject areas to illuminate the theoretical underpinnings for the project. To satisfy that need, this review chapter will be organized as follows. First, a discussion of research in teaching and modeling general problem solving is presented, followed by an examination of the relationship of these findings to transfer of knowledge. A discussion of medical clinical problem solving ensues, and the commonalities and differences between medical and dental clinical problem solving are discussed. A summary of the theoretical bases and evidence for transfer of biological knowledge to dental clinical problem solving completes the chapter.

Theoretical Foundations

Teaching Problem Solving

A small portion of the anecdotal history of concern for teaching critical thinking and problem-solving skills was presented in Chapter I. For many years, educators theorized that some sort of "mental muscle" existed which could be exercised with appropriate academic work to develop reasoning ability (Mann, 1979; Nickerson, 1984). It was later acknowledged that, for instance, Latin or mathematics scholars, who had labored long at exercising that presumptive muscle, rarely demonstrated problem-solving abilities outside their own areas of expertise. This recognition spurred on the search for those elusive, teachable skills which could enhance a learner's ability to solve problems of any nature (Bransford et al., 1985; Mann, 1979).

There has not been agreement among problem-solving researchers about the existence of teachable process skills in critical thinking which are transferable to any number of subject domains. Halpern (1987) argues that there are a number of recognizable critical thinking skills which are teachable and applicable in more than one domain. Her list of these skills includes understanding cause-effect relationships, recognizing assumptions, analyzing means-goals relationships, reducing complex problems to simpler ones, and using analogies to aid in problem solving. Yet, Halpern (1987) casts doubt on the transference of the skills by concluding, for example, that it is not known whether

teaching the use of analogies in the comprehension and recall of scientific information helps students to generate their own analogies spontaneously as an aid in future recall and transfer. A possible explanation for this instance of lack of evidence for transfer may lie in a theory of training learning abilities, explained by Derry and Murphy (1986). The theory distinguishes between learning strategies and learning tactics. Whereas learning strategies are conceived as broad, general plans one uses to exercise control over thinking processes in learning situations, learning tactics are more specific skills (perhaps subject specific skills) that may not be easily transferred outside that domain. It may be that Halpern's list of skills represents tactics rather than strategies; therefore, they would not be expected to be transferable.

Other investigators would agree with Halpern's assertion that there exist process skills for critical thinking or problem solving which are independent of discipline-specific content. A partial list of these investigators would contain the names of Dewey (1933), Bloom (1950), Dressel and Mayhew (1954), Polya (1971), Rubinstein (1975), Feuerstein, Rand, Hoffman, and Miller (1980), Yinger (1980), Whimbey and Lochhead (1982), Nickerson (1984), Bransford and Stein (1984), and Sternberg (1985), with reservations. The specific contributions of some of these researchers are discussed in a subsequent section.

In a recent article reviewing findings on the interaction of developing problem-solving skills and the acquisition of domain-specific knowledge, Glaser (1984) maintained that thinking skills are learned primarily through the acquisition and application of a particular knowledge base. He did allude to the possibility that mature learners can benefit from instruction in the use of self-regulating procedures or metacognitive skills which monitor progress in one's thinking or problem solving. However, Glaser's primary thesis was that the role of specific knowledge is central to developing thinking abilities. He is joined in that position by other researchers such as Gagne (1977), Resnick (1983), Greeno (1985), and Mayer (1987). Yet other researchers in this field have concentrated their investigations on the differences between experts and novices in content-specific domains (see, for example, Bhaskar & Simon, 1977, engineering; Chi, Feltovich, & Glaser, 1981, physics; Larkin, McDermott, Simon, & Simon, 1980, physics; Lesgold, Feltovich, Glaser, & Wang, 1981, radiology; Mayer, 1987, mathematics; Norman, Tugwell, Feightner, Muzzin, & Jacoby, 1985, clinical medicine; Voss, Greene, Post, & Penner, 1983, social sciences). While many of these authors have not addressed the issue of transfer of problem-solving skills, they all have considerably illuminated understanding of expert and novice performance in their fields of interest, thus providing theory-building research towards the process of problem solving.

The literature cited in this section leaves this researcher with the impression that some problem-solving theorists are inclined to adopt an either/or attitude in formulating theoretical concepts. One illustrative example is the assertion: either there are or are not teachable skills in problem solving exclusive of subject content. It is not surprising that difficulty is encountered in confirming such polarized theories in research. The next section describes the work of other researchers who have developed models of problem solving and have elucidated the necessity of knowledge in teaching problem-solving skills.

General Problem Solving Models

Modeling the process of problem solving involves the categorization of discrete cognitive activities into several groups for ease of understanding, learning, and discussion. Many researchers have presented models organized for easy characterization. A few of these models will be presented to provide a basis for discussion and consolidation.

Dressel and Mayhew (1954, pp. 179-180) identified five types of mental activity which were presented as skills of critical thinking:

1. The ability to define a problem.
2. The ability to select pertinent information for the solution of the problem.
3. The ability to recognize stated and unstated assumptions.

4. The ability to formulate and select relevant and promising hypotheses.
5. The ability to draw conclusions validly and to judge the validity of inferences.

Another set of descriptive categories was provided by Polya (1971) which included questions to ask oneself during problem solving:

1. Understand the problem. Ask yourself what is known and unknown; what conditions exist?
2. Devise a plan. Look for a related problem that has been solved before. Could you use it?
3. Carry out the plan. Try out your solution plan, checking each step.
4. Look back. What results and arguments can you check which indicate a satisfactory solution?

In a presentation which outlines a plan for teaching problem solving in a subject context, Woods (1987) offers his holistic approach:

1. Learn of the occurrence of a problem.
2. Define the given problem.
3. Define the "real" problem and create a representation of it.
4. Plan for a solution.
5. Carry out the solution.
6. Check, look back, and implement a better solution.

Bransford and Stein (1984) have created a model identified by the acronym IDEAL, which emphasizes five

components of thinking they believe are applicable to a wide variety of situations:

1. I = Identification of problems. Paying attention to cues that do not make sense or that do not fit with current knowledge.
2. D = Definition of problems. Defining affects the way a problem is perceived and worked out.
3. E = Exploration of strategies.
 - a. Creating manageable subproblems
 - b. Examining special cases
 - c. Working backward
 - d. Identifying assumptions and inconsistencies
4. A = Acting on ideas, based on strategies.
5. L = Looking at the effects.

As part of a program recently designed for training arithmetic problem-solving skills, Derry and Murphy (1986) have outlined specific skills that they stress in their program:

1. Clarify the problem. Categorization, goal identification, and evaluation of information are involved.
2. Choose a solution procedure. Apply problem heuristics (rules of thumb).
3. Carry out the solution method. Use persistence, strategies, and careful work.
4. Check work. Use estimation of solution and a review strategy.

In their book entitled Concepts in Problem Solving, Rubinstein and Pfeiffer (1980) provided yet another problem-solving model:

1. Perceive and analyze problem components.
2. Formulate hypotheses about possible solution paths.
3. Select among the hypotheses.
4. Test the most likely hypothesis.
5. If all tests fail, rethink the first two steps.

Other, quite similar models have been reported (see, for example, Belmont, Butterfield, & Ferretti, 1982; Holyoak, 1984; Lochhead & Whimbey, 1987). Only more recently has it been pointed out that general problem-solving strategies, standing alone, are not effective for teaching and learning problem solving. Derry and Murphy (1986, p. 27) have referred to these most general problem-solving steps as "weak solution methods." The more general the model, the more fuzzy and imprecise are the ways of responding to a particular problem.

One aspect of problem solving has been avoided or only hinted at in all but the most recent literature. That is the skill nature of problem solving. If problem solving is indeed a skill, as many have assumed, then it should be recognized that improving the skill requires practice. One can first practice recalling the process skills of problem solving, that is, the strategies, sequences, and self questioning learned for general problem solving. Second, in order to have practice at solving actual problems, it is

necessary to use the skills within a domain of knowledge, such as science, math, or clinical dentistry. Only recently have researchers recognized that programs structured to teach thinking and problem solving can be improved by focusing more on domain knowledge and its role in learning to solve relevant problems (Bransford et al., 1986). This leads to the next topic of review, the transfer of knowledge in problem solving.

Transfer

The question of how to teach for transfer of knowledge is an intriguing one which has occupied cognitive researchers for at least a decade. Weaver (1987, p. 583) stated the thrust of current efforts in transfer of training when she recognized "the need to teach within a 'metacognitive environment,' one that emphasizes not only training and practice in the skills taught but also self regulation and awareness of the utility of the trained skill." Following this line of reasoning, Perkins and Salomon (1987, 1988) have formulated a theory of transfer that distinguishes between two mechanisms, which they term "low road transfer" and "high road transfer." According to this theory, low road transfer occurs automatically as the result of practicing variations of a skill. To demonstrate this mechanism they offer the example of having practiced driving a car in a variety of situations, then transferring many of the same skills to driving a truck. The similarities of the experiences overlap, allowing automatic transfer of many driving skills.

High road transfer, on the other hand does not happen automatically, but requires mental effort by the learner to recognize a principle and form an internal representation of it that allows generalizing to a range of situations. This abstract representation is thought to act as a bridge between the learning context and a new application. An example of facilitating high road transfer should be familiar to graduate students: How can multiple regression models be applied to one's domain of interest, such as evaluation of information gathered in a clinical problem? Asking such metacognitive questions begins the bridge-building between the domain of statistical theory and its application to the domain of the learner.

In medical and dental education inert knowledge has been a difficult problem. Traditionally, these students memorize list upon list of facts about basic medical science, in disciplines such as physiology or anatomy, without any exposure to the future diagnostic applications they will need to make. This has prompted at least one medical school to adopt a problem-based learning approach to basic medical science (Barrows & Tamblyn, 1980). In this setting medical students acquire technical knowledge of the human body by working through problem cases which require diagnosis.

The problem-based approach is intended to satisfy the prerequisite for problem solving--that appropriate knowledge must be accessible in memory when needed. Several variables in the learning process have been identified as having

importance in developing cognitive structure which facilitates access to knowledge (Mackenzie, 1986). Understanding the purpose for learning new information can help a person process it for later access, as can the intrinsic motivation for learning the material. Also, directing attention to important concepts and their relationships, forming images associated with concrete concepts, increasing meaningfulness through association with several other concepts, and using contexts appropriate for the desired transfer when giving examples are all important factors affecting recall. Perhaps the most influential variable in transfer-appropriate processing of information is overlearning, the extensive and varied practice of recalling information beyond that needed for adequate performance. Finally, the active use of metacognitive strategies during learning can improve access. Such mental activities as elaboration, forming associations and images, and fitting new information to that already known exemplify metacognitive strategies known to aid recall (Bransford, 1979; Mackenzie, 1986). It has been recognized, however, that such metacognitive strategies are difficult to teach; they must be gradually developed over an extended period with copious amounts of guided practice in the desired range of applicability (Derry & Murphy, 1986). The variables discussed above formed the basis of the differential treatment design for which the BioTrans test was used to

detect the effects of the treatment. The study design is described in detail in Chapter III.

Medical Clinical Problem Solving

There has been a great deal of research in medical problem solving in the last two decades. One of the earlier, influential studies was conducted by Elstein, Shulman, and Sprafka (1978). From a detailed study of a small group of physicians and medical students solving a few clinical problems, they developed conclusions which guided the direction of further research for some years. First, the study described a general information processing model of medical inquiry which has four important stages: cue acquisition, hypothesis generation, cue interpretation, and hypothesis evaluation. Cue acquisition involves the collection of pertinent data, not all of which is immediately available at the start of the patient encounter. Hypothesis generation relies on retrieval of likely diagnoses from memory by an associative process. Cue interpretation was thought to be a form of pattern matching with known disease processes which would either confirm or disconfirm a hypothesized diagnosis. Hypothesis evaluation was meant to describe the procedure of choosing among the likely diagnoses generated. The process has been termed the "hypothetico-deductive method."

A second finding was that the correlations between performance scores on dissimilar medical problems were low. This finding was interpreted to mean that there is little

transfer of clinical problem-solving skills from one problem domain to another. Several other studies appeared to confirm this interpretation using varied methods of performance scoring and patient formats (Berner, Bligh, & Guerin, 1977; Donnely, Fleisher, Schvenker, & Chen, 1982; Norcini, Swanson, Grosso, & Webster, 1983; Norman & Tugwell, 1982; Skakun et al., 1979).

More recently, disagreement has prevailed in the medical education literature about the existence of functioning general problem-solving skills in solving different types of clinical problems. Norman (1985b) reviewed the medical problem-solving literature, introduced a theory from the psychology of expert reasoning, and contrasted this approach with the hypothetico-deductive theory of medical problem solving. He concluded that the experienced clinician is better at solving clinical problems, not by virtue of any innate or learned skill, but by a gradual accumulation of experience which allows better perception, organization, and recall of patient information and relevant knowledge.

Yet, in another article published the same year, Norman and other colleagues (Norman, Tugwell, Feightner, Muzzin, & Jacoby, 1985) appeared to relent somewhat in such stringent interpretations about the lack of transfer of problem-solving skills. They concluded:

Instead, it would appear that this issue is not one of limited transfer of knowledge, but is related to the inherent, and apparently random, variability present in performance on a single problem. At best, this variation may simply represent a measurement problem,

and a better choice of measures may improve generalizability. (p. 354)

In other words, the method of measuring performance did not anticipate the range of variability in each clinician's problem-solving applications. False conclusions about the generalization of ability from one type of problem to another may have resulted.

Similarly, in the same year McGuire (1985) criticized the narrowness of medical problem-solving studies and the validity of their conclusions. Her review characterized the hypothetico-deductive method as a five-step process in which the clinician

1. begins with an initial impression or concept,
2. formulates a limited number of hypotheses (diagnostic impressions),
3. uses these hypotheses to direct the search for additional data,
4. interprets the data collected, and
5. refines, verifies, revises, rejects, or re-ranks the hypotheses, leading to a working diagnosis.

McGuire's criticisms centered around the methodology of most of the studies. Nearly all of them used microscopic analyses of data from small numbers of clinicians with a few real or simulated patients. She pointed out that these studies are too limited to draw the generalizations they present, and provided evidence that an audit of at least 10 cases may be necessary to produce a stable estimate of clinical performance. In her summary, McGuire (1985) stated:

it must be concluded that the studies reported to date and the methodology employed in those studies raise many troublesome questions and leave unilluminated a large portion of the universe of activities in which physicians engage between initially seeing a patient and finally resolving that patient's problem. (p. 592)

In an attempt to clarify the contradictory and sometimes puzzling results of two decades of studies, Barrows and Feltovich (1987) presented a model of the clinical reasoning process which they believe is consistent with past research in the process, novice-expert differences, clinical experience, and artificial intelligence modeling of clinical reasoning. They emphasized that it is essential to recognize that in most patient encounters, needed information is not available at the outset, but gradually unfolds through investigation. Furthermore, the problem-solver may never be assured that a solution has been reached, because many problems are not clear cut, but are ill-structured. The authors claim that the use of well-structured simulated patient problems to measure performance will not be indicative of performance in actual practice.

The model of the clinical reasoning process presented by Barrows and Feltovich (1987) contains the following elements:

1. Initial patient presentation. Several initial hypotheses as to the cause of the patient complaints are generated. The hypotheses may be of an anatomical or physiological nature, or may be general or specific diagnoses.

2. Hypothesis-oriented inquiry. The guides for further questions, examination, and tests result from a combination of problem-driven questions and menu-driven questions (such as a standardized review of systems inquiry).
3. Internal representation of the problem. All data acquired concerning the problem is synthesized into an understandable model of the patient's medical condition, which can be compared to that expected under the working hypotheses. Underlying pathophysiological mechanisms are considered which further shape the representation and direct additional inquiry. This type of process continues until the clinician has proceeded from an initially ambiguous diagnostic situation to the point where a diagnostic decision can be made. The approach of each clinician will vary as information is obtained and the problem representation continues to be shaped.
4. Diagnostic decision. By now most clinicians would agree on the underlying pathophysiologic mechanisms at work, and perhaps on the diagnosis. The expert, with greater experience in the variability of disease presentation, may reach a decision more quickly than the novice.
5. Laboratory tests and treatment management decisions. The clinical reasoning process is extended while

results of tests are reached, and a working diagnosis has been established as treatment begins.

Most of the studies in clinical reasoning deal primarily with formulating a definitive diagnosis, and few deal with the treatment or management of the patient. Thus, most medical problem-solving models do not go beyond the diagnosis stage. This is true because once a diagnosis has been made, it usually leads to a specified course of treatment (Ettinger, 1984). As is discussed later, this represents a major point of departure between clinical medicine and clinical dentistry.

Barrows and Feltovich (1987) address other controversial issues in clinical problem solving as well. Some researchers have claimed that the reasoning process used by medical clinicians resembles more the pattern matching process than the hypothetico-deductive process (see, for example, McGuire, 1985; Norman, 1988). Also, it has been claimed that multiple hypothesis formation and deductive reasoning are used by the novice, whereas the expert uses a different process. The authors refute these claims by asserting (but not demonstrating) that such differences only appear to be present because experienced clinicians have automatized many of the steps and do not express them when asked to think aloud while problem solving. Finally, the authors underscore the relationship between reasoning and knowledge by emphasizing that the medical expert relies on extensive, well

integrated knowledge bases as well as the reasoning process outlined above.

Missing in these discussions in the medical problem-solving literature is any evidence of attempts to teach the use of well-defined principles of medical problem solving and guided practice in the use of these principles in many different medical disciplines. If this type of teaching were implemented and evaluated, then one might expect to be able to measure the transfer of general skills across problem domains. Such research could resolve some of the controversies and criticism associated with narrow methodologies and broad interpretation.

Dental Clinical Problem Solving

Reports of studies of the clinical problem-solving process or of transfer of training to clinical problem solving in dentistry are sparse (Ettinger, 1984; Kress, 1980). Until recently, studies about decision making in dentistry have been confined to practice management aspects of dental practice, such as students' choice of occupation, practice location, appointment book control, quality control of clinical treatment, and cost control of dental care (see Ettinger, 1984 for a list of citations). Mendel and Scheetz (1982) presented a study on the effects of seminars and computer-assisted instruction on endodontic problem solving in dental students. However, their study was concerned with improving a specific type of diagnosis and did not address the general process of clinical problem solving. Chambers

(1987) described issues in transfer of training from preclinical laboratory to clinical application, but the article was primarily confined to transfer of psychomotor skill training.

Milgrom and colleagues (Milgrom, Kiyak, Conrad, Weinstein, & Ratener, 1981) reported great variability in treatment planning by over 400 general dentists. The authors could not account for this variation by attitude, training, or experience of the dentists. They suggested that little is known about dentists' clinical decision-making processes and that training in data reduction and integration should be part of the dental student's experience.

Mackenzie (1975) provided guidelines for developing tests of clinical judgment, particularly written patient simulation problems, with the objective of increasing dental educators' abilities to assess systematically the clinical judgment of dental students. This volume dealt primarily with measurement issues, rather than with modeling the process of problem solving.

An evaluation of written patient management problems for use in assessing clinical judgment was reported by Adams, Wills, Shannon, Hadac, and Weinstein (1979). However, the study was concerned with testing acceptance and the feasibility of using such problems, but not with the clinical judgment process. Written patient management problems have been used or tested in at least five North American dental schools (Adams et al., 1979), either for the convenience of

testing clinical performance simultaneously for large groups of students, or to provide students with a wider variety of experience with clinical problems than the dental school can provide via its patient pool.

A descriptive discussion of the need for including formal instruction in the underlying principles of problem solving was provided by Taintor, Taintor, and Biesterfeld (1980). These authors argued that even though diagnostic and treatment planning principles for each dental discipline are thoroughly taught in dental schools, the formal steps associated with identifying and applying these general principles are lost to the student, to the detriment of future dental practice. They offered a general model of problem solving applicable to dental clinical use:

1. Recognize, limit, and define the problem.
2. Analyze and evaluate the problem.
3. Establish criteria by which the solution will be evaluated as acceptable.
4. Collect data.
5. Implement the solution.

Citing a survey of diplomates of the American Board of Endodontics, it was pointed out that 65 percent of those surveyed indicated that diagnosis was the most difficult area in their practice. These board-certified practitioners had demonstrated their knowledge base and understanding of basic science principles. Yet, their responses suggested to the authors that the lack of understanding the process of

diagnosis indicated a need that dental school programs should satisfy.

Mackenzie (1980) described the events in dental education leading to the establishment of oral biology departments in dental schools, a movement designed to promote better correlation between basic and clinical sciences in dentistry. He then presented in detail the findings of cognitive science research and the instructional principles derived therefrom that are related to improving transfer of biological knowledge to clinical practice. The resulting curriculum suggestions were put into practice in the University of Florida College of Dentistry in 1981, and formed the basis of differential treatment, which is a subject of investigation in the present study. The differential treatment is described in detail in the methodology section.

In a recent article, Ettinger (1984) discussed general principles of problem solving and decision making and their applications to dental diagnosis and treatment planning. He pointed out the lack of research in dental decision making and proposed a model of the process:

1. Patient seeks treatment
2. Diagnosis (problem solving) proceeds by either
 - a. the anatomical model (site, size, shape, etc. of a lesion), or
 - b. the medical model (obtaining data about the host

and environment, disease or lesion, and host-disease interaction)

3. Treatment planning (decision making) for purposes of prevention, cure, palliation, or reconstruction
4. Treatment
5. Observation of outcomes
6. Maintenance procedures.

The model appears to present an either/or scenario; that is, it represents the dentist as using either the anatomical model or the medical model in diagnosis. In practice, both models are used together. However, the model and its description point out a fundamental difference between medical and dental clinical problem solving. Traditionally, medical problem solving has been concerned primarily with identifying disease processes. Once the diagnosis has been made, the course of treatment is generally clear and specific. Until recently, the emphasis in dental problem solving has been on determining the course of treatment from among many alternatives, once the rather straightforward diagnosis has been made. The diagnosis was usually concerned with dental caries (decay), periodontal disease (disease of the bone and soft tissue supporting the teeth), and their sequelae. Lately, changes in the epidemiology of these traditional oral diseases, coupled with an increased demand to treat persons who are medically, psychologically, or functionally compromised, or who have chronic forms of orofacial pain, have altered the practice emphasis in

dentistry. These additions to the lexicon of dental practice require more effort in the diagnosis aspect of problem solving. While Ettinger's article is directed toward decision making in dental treatment of the elderly, his conclusions apply to all aspects of dental care. He has concluded, for example, that research is needed in dental clinical decision making and in measuring outcomes of treatment, which will, in turn, affect future clinical problem solving. He also has suggested that the groundwork laid in the use of written medical patient management problems or simulations can be productively utilized in extending this needed research base.

A summary of the problem-solving models presented, indicating their similarities and differences, is provided in Table 1. Each element of the table is derived from the general problem-solving scheme presented in Chapter I, and each of the models can be readily partitioned into the categories shown. Inspection of the table indicates that all models have steps categorized as data gathering, hypothesis formation and hypothesis testing. Two models (Polya, 1971; Derry & Murphy, 1986) do not specify a problem recognition step, because these models assume that a problem has already been presented. The three medical problem-solving models (Barrows & Feltovich, 1987; Elstein et al., 1978; McGuire, 1985) and one general dental problem-solving model (Taintor et al., 1980) do not indicate outcome evaluation steps. This has likely occurred because medical models are concerned

TABLE 1

Classification of elements of problem solving models

Elements					
Author(s)	Problem Recognition	Data Gathering	Hypothesis Formation	Hypothesis Testing	Solution Evaluation
Dressel & Mayhew, 1954	Define a problem	Select information, recognize assumptions	Formulate & select relevant hypotheses	Draw conclusions	Judge validity of inferences
Polya, 1971		Understand the problem	Devise a plan	Carry out the plan	Look back to check
Woods, 1987	Learn about the problem	Define problem, create a representation	Plan for a solution	Carry out the solution	Check, implement a better solution
Bransford & Stein, 1984	Identify a problem by cues	Define the problem	Explore some strategies	Act on the strategies	Look at the effects
Derry & Murphy, 1986		Clarify the problem	Choose a solution procedure	Carry out the solution method	Check work, review strategies

TABLE 1

Continued

Author(s)	Elements			
	Problem Recognition	Data Gathering	Hypothesis Formation	Hypothesis Testing Solution Evaluation
Rubinstein & Pfeiffer, 1980	Perceive a problem	Analyze its components	Formulate hypotheses about solutions	Test the most likely hypothesis If tests fail, rethink the first steps
Elstein, Shulman, & Sprafka, 1978	Cue acquisition	Cue interpretation	Hypothesis generation	Hypothesis evaluation, choose working diagnosis
McGuire, 1985	Initial impression	Form diagnostic impression, collect additional data	Interpret data	Form working diagnosis
Barrows & Feltovich, 1987	Initial patient presentation	Hypothesis oriented inquiry, internal representation	Diagnostic decision	Laboratory tests & patient management decisions

TABLE 1

Continued

Author(s)	Elements			
	Problem Recognition	Data Gathering	Hypothesis Formation	Hypothesis Testing Solution Evaluation
Taintor, Taintor, & Biesterfeld, 1980	Recognize problem	Limit & define problem, collect data	Establish criteria for acceptable solution	Implement the solution
Ettinger, 1984	Patient seeking treatment	Anatomical & medical diagnosis	Treatment planning	Carry out treatment Outcome evaluation & maintenance

primarily with diagnosis; the follow-up evaluation is concerned with the outcomes of treatment.

In 1986, an entire issue of the Journal of Dental Education was devoted to the topic of basic sciences and the dental curriculum. Several of the articles underscored the need for revising the dental schools programs to achieve a much greater transfer of basic science knowledge to the judgment, reasoning, and decision-making tasks of clinical practice (DePaola, 1986; Fischman, 1986; Neidle, 1986; Roth, 1986; White, 1986). Neidle (1986) stated her perception of the problem as a basic scientist and administrator:

What's the problem? In a word, everything. For 65 percent of our students in 42 schools, the basic sciences are taught in medical schools or health science centers and their relevance to a dentist's present and future needs is tenuous and inconsistent. . . . The remaining 35 percent of students take their basic sciences from dental school departments that are increasingly under fire as being financially burdensome to the school and probably eminently expendable. (p.455)

Roth (1986) presented the problem from the viewpoint of a clinician and administrator:

A climate of student disaffection [with basic science] results in those same students entering practice without an appreciation for the biologic basis of dentistry, or for the scientific method and its importance. Students graduate without the spirit of inquiry, without healthy skepticism, and without the ability to evaluate critically. (p. 462)

The Association of American Medical Colleges had come to similar conclusions earlier (AAMC, 1984) regarding medical training. Also the need for new methods of assessing revised programs and student clinical performance was recognized (Norman, 1985a, 1987). Similarly, new evaluation measures

are required for assessing new programs designed to increase transfer of biological science knowledge to clinical practice in dentistry.

Summary

Recent research has shown that there is more to problem solving than the possession of a set of general strategies, applicable in any situation. The foundation of problem-solving abilities is a strong knowledge base appropriate to the domain of the problem. The capstone to that foundation is that the problem solver have effective access to the appropriate knowledge base. Access is improved when learning occurs under certain conditions, such as when specific teaching, learning, and recall strategies are utilized which are known to improve understanding and retrievability of information. Thus, effective problem solving depends a great deal upon the quality and quantity of knowledge available to a person when attempting to solve a problem.

Educators in medicine and dentistry have expressed concern about the apparent failure of their programs to graduate practitioners with excellent clinical problem-solving abilities. A major contributor to this dilemma appears to be the lack of transfer of basic biological science training to clinical practice. This recognition has given rise to revision of some programs to include problem-based training, development of analytical skills, and training in developing problem-solving strategies. There is

an accompanying need for valid, reliable instruments to evaluate the effectiveness of the revised programs.

A tabular display of the elements of problem-solving models was presented to indicate how problem-solving theories were integrated into a structural framework upon which the BioTrans instrument was constructed. The elements of this instrument are described in Chapter III.

CHAPTER III METHODOLOGY

Development of the Test Instrument

The first objective of this study was to develop and validate a test instrument for measuring transfer of biological knowledge to the activity of solving clinical problems by dental students. Review of the literature provided a theoretical basis for the general model of clinical problem solving which became the structural framework for the instrument. The general model had five elements derived from common features of general and clinical problem-solving models:

1. Recognizing or identifying a problem.
2. Gathering data about the problem and restating it in the formal terminology of the domain.
3. Forming causal hypotheses and planning for problem solving by applying chosen principles.
4. Testing the hypotheses by carrying out the plan.
5. Evaluating the outcome of the plan.

A set of questions was adapted to these structural elements to form the BioTrans test, reflecting the use of the elements in solving simulated clinical patient management problems (Appendix A).

Senior dental students at the University of Florida College of Dentistry (UFCD) must complete a module on evaluation of clinical judgment as a requirement for graduation. Part of the requirements for successful completion of Module 858 (Evaluation of Clinical Judgment) are to manage properly several comprehensive patient-oriented problems with written responses of diagnosis and patient management decisions. The student is provided clinical materials, such as patient history, examination findings, radiographs, mounted dental models, photographs, and laboratory reports, and is asked to describe and justify a sequence of steps for managing the patient problem.

Problem Recognition

The test instrument questions (BioTrans test, Appendix A) were developed for use in the Module 858 test setting. Questions I.A. and I.C. ask for identification of cues utilized in problem recognition and identification. Questions I.B. and I.D. query the students' application of biological concepts to the problem cues identified.

Data Gathering and Hypothesis Formation

An active review of the data is encouraged in question II.A. followed by formation of diagnoses (hypotheses). Parts B and C of question II ask the student to connect biological concepts with the chosen diagnoses, and with the consequences of failure to treat the problem.

Testing Hypotheses and Evaluating the Outcomes

Question III.A. asks that therapy and management of the patient problem be summarized. Due to the nature of the patient management problem, the hypotheses cannot actually be tested by carrying out treatment. Thus, a plan for carrying out treatment is substituted in this situation. Planning of treatment also includes considering potential events which could require alteration of the plan. This step encourages thinking about such eventualities, and question III.B. is intended to stimulate responses linking biological concepts to such events. Question III.C. substitutes for actual monitoring of treatment outcomes by requiring responses associating biological concepts with cues to be monitored during follow-up.

Content Validity

A draft set of instructions and test questions was submitted to seven dental clinical faculty, the chairman of the dental education department, and two graduate students in dentistry for review and recommendations for revision. Action was taken on suggestions to include a cue-directed approach to elicit more easily connections with biological concepts, to clarify question terminology, and to clarify the test instructions.

The revised test instrument underwent trial testing by 10 junior dental students as follows. The junior students were volunteers responding to a notice offering a 50 dollar cash prize to be awarded, after the trial was completed, to a

randomly chosen volunteer from among the first ten. Each examinee was asked to recall a clinical case from his or her own experience which involved some degree of comprehensive care. This substitution avoided disclosing the content of any patient management problems used for this study or to be used during any subsequent Module 858 test program.

Employing the recalled case as a problem case, the examinees responded to the instructions and test questions in writing. Upon completion of each test administration, the researcher briefly interviewed the examinee to determine whether difficulties were encountered in completing the test. It was found that the wording of two test questions required clarification. In addition, several changes became necessary in the wording of the instructions to clearly define the meaning of the term "biological concept." Also, it was necessary to provide some example responses in the instructions to indicate the type and range of responses desired for the test. The example responses were drawn from the discipline of orthodontics, a field which would not be included in the patient management problems to be used for this study.

After each interview, the test and instructions were revised for the next trial, repeating this process until the 10 volunteers had completed the trial. In this manner each revision had more than one trial. The resulting instrument was prepared for use in Module 858 in the form that now appears in Appendix A.

Validation of the Test Instrument

Validating Instrumentation

Functional Job Knowledge Test (FJKT). This test uses the critical incident technique to measure use of biological knowledge. By responding to a short set of open ended questions, the respondent is asked to recall a clinical episode for which biological knowledge made a difference in patient care. Thus, it is a context-sensitive instrument by nature of the use of clinical episodes. Validation studies (Mackenzie, 1965) showed that content analysis of responses detected differences between students from different dental schools ($p < 0.0001$). In contrast, analysis of responses of juniors compared to seniors in the same schools showed no significant differences. A system for categorizing thought processes has been developed using FJKT responses (Mackenzie, et al., 1986). Validity for the system was tested by comparing data collected from a group having more training in clinical thinking and judgment with a group having less. Using very specific criteria, five judges could categorize data reliably at the 85 percent agreement level. The FJKT tests were administered to senior dental students earlier in the senior year than the Module 858 tests, under nearly identical test conditions in the testing center. A sample of the FJKT is found in Appendix C.

Word Association Test (WAT). This instrument is commonly used to measure memory organization in a context-free setting. Memory organization is an important factor in

transfer of learning to a new setting. A probe task or concept is printed on the test sheet, and the respondent is asked to write down as many words or ideas related to the probe as possible, in a one minute time period. The responses are categorized by content analysis. Shavelson (1974, p. 241) has presented ample validation evidence for the interpretation of word-association data as a representation of cognitive structure (memory organization). This researcher has used the WAT in another validation study (Mackenzie, Martin, & Gale, 1988). In the present study the WAT was administered to the senior students during the Module 858 testing. A sample of the WAT is found in Appendix C.

Test Scoring

The responses on the three types of tests (WAT, FJKT, BioTrans) were content analyzed in a blind fashion by placing the response concepts into one of four categories: basic biological concepts, applied biological concepts, clinical tasks, or other concepts. Decision rules for categorizing concepts were as follows.

1. Basic biological concepts are those concepts which pertain to or describe the structure and/or function of the human organism. Examples of basic biological concepts are endochondral bone, bony sutures, osteoblasts, bone mineralization, blood supply, inflammation, insertion and attachment of muscles, in other words, key concepts learned in basic biological science courses, such as anatomy or physiology.

2. Applied biological concepts are those biologically oriented concepts which are of particular importance to, or describe the structure and/or function of the human stomatognathic system, the system of primary concern for the dentist. Examples are orthodontic treatment forces, skeletal malocclusion, saliva, calculus, or dental pulp.

3. Clinical tasks are the specific activities that the dentist performs while carrying out the duties of patient care, that is, diagnosis, treatment planning, treatment, and follow-up care. Examples are cavity preparation, tooth restoration, occlusal equilibration, gingival surgery, radiographic examination, and clinical discipline phrases such as endodontic treatment or periodontal surgery.

4. Other concepts are those responses that do not fit the first three categories. They include tools and materials used in dentistry, such as impression materials, resins, matrix materials, explorers, forceps, and film developer. Rules for counting biological concepts were those specified in a classification system developed by Mackenzie et al. (1986); pertinent excerpts are provided in Appendix B.

Placement of concepts into the four categories was done to facilitate data analysis for future studies. For the purposes of the present study a single test score for each of the three tests (BioTrans, WAT, FJKT) was formulated by summing the number of basic and applied biological concepts.

To ascertain scoring consistency, 10 percent of the subjects' test sets were blindly scored a second time at

least two weeks after the first scoring. Scoring consistency was determined by the percent agreement between initial and second ratings.

Validation Data Analysis

Construct validation involves making a series of predictions, based on theory, about the relationship between results on instruments which measure the same or similar constructs (Crocker & Algina, 1986; Thorndike & Hagen, 1969). The predictions or hypotheses are made about correlations between measures, differences between groups, and responses to experimental interventions, and are tested by obtaining experimental data utilizing the instruments. In the present study, hypotheses about correlations and about responses to experimental interventions were made.

The review of the literature discussed the theoretical basis of the relationships between problem solving, knowledge bases, cognitive structure, and transfer of training. Upon this theoretical basis the investigator formulated hypotheses about correlations between the BioTrans test and two measures of cognitive structure, the WAT and the FJKT. It was reasoned that instruments measuring the organization of biological information in memory would correlate positively with a measure of transfer of biological information to the problem-solving process. Because the final class rank of the dental students is based largely on clinical performance, it was reasoned that scores on the BioTrans test would be predictive of class rank by correlating positively with the

ranks. Experimental interventions conducted while the students learned biological concepts were expected to produce differences in cognitive structure, and therefore, differences in access to, and transfer of the concepts in clinical problem solving. The reasoning was that these differences in cognitive structure of biological information would be expressed by differences of frequency of recall of concepts applied to solving clinical problems. Thus, it was hypothesized that concepts learned under each of three learning conditions would have differential frequencies of appearance in test responses. The three learning conditions are described later in the section concerning learning interventions. Experimental results which support these predictions provide evidence for construct validity of the BioTrans instrument.

The first research question of this study was, are the scores on the BioTrans assessment instrument related to scores on an existing context-sensitive measure of cognitive structure, the FJKT? The hypothesis associated with the question was stated in the directional form: The Pearson product-moment correlation coefficient between scores on the BioTrans test and scores on the FJKT is greater than zero at $\alpha = .05$, as evidence of construct validity. The correlation coefficient was calculated and interpreted. Crocker and Algina (1986, p. 231) described one approach to construct validation in which the correlation between a

measure of a related construct and the designated test instrument can be interpreted as a measure of validity.

The second research question was, are scores on the BioTrans instrument related to scores on an existing context-free measure of cognitive structure, the WAT? The associated hypothesis was stated in the directional form: The Pearson product-moment correlation coefficient between scores on the BioTrans test and the WAT is greater than zero, at $\alpha = .05$. The correlation coefficient was calculated and interpreted. Crocker and Algina (1986, p.224) identified concurrent validity as the relationship between test scores and those on a criterion measure, both measures obtained at the same test time. A sufficiently high positive correlation between the scores can be considered as evidence for concurrent construct validity.

The third research question was, are scores on the BioTrans instrument related to the final class rank of the examinees? The associated directional hypothesis was: The Spearman rank-order correlation coefficient between scores on the BioTrans test and final class rank of examinees is greater than zero, at $\alpha = .05$, as evidence of predictive criterion-related validity. Crocker and Algina (1986, p. 224) described predictive validity as the degree to which test scores can predict values of a criterion measure which will be obtained at some future time. Moderate, positive correlations between measures are one indication of predictive validity. The criterion measure of final class

rank was thought to be meaningful, because it represents a rank score which is heavily weighted by clinical evaluations, reflecting an emphasis on clinical performance. Thus, the final class rank is thought to be an overall rating of clinical competence by administrators, and therefore can be construed as a measure of clinical problem-solving competence. The Spearman rank order correlation coefficient is used to determine correlations between scores, both of which are measured on an ordinal or higher scale of measurement. The Spearman Rho value was calculated and interpreted.

The fourth research question was, are scores on the BioTrans instrument stable when examinees are tested on separate problems? The corresponding directional hypothesis was: The Pearson product-moment correlation coefficient between scores on the BioTrans test for two separate patient management problems is greater than zero, at $\alpha = .05$. One definition of reliability is the degree of stability of scores between equivalent forms of a test administered to the same examinees at the same testing (Crocker & Algina, 1986, p. 117). While the two patient management problems used in the study are not equivalent, they can be considered parallel forms for the purpose of stimulating recall of biological concepts. The correlation coefficient between the two sets of scores is considered a measure of reliability. The Pearson product-moment correlation coefficient was computed and interpreted.

The fifth research question was, do the results of the BioTrans test reflect the effects of differential treatment when learning biological concepts? The related null hypothesis was: There are no differences in the mean number of reported biological concepts learned by each of three different methods, at $\alpha = .05$. Rejection of the null hypothesis provides evidence for construct validity of the instrument by demonstrating the predictions of changes occurring as a result of experimental interventions (Thorndike & Hagen, 1969, pp. 176-177). The data were analyzed by repeated measures analysis of variance.

Experimental Methods

Experimental Design

The second objective of this study was to determine whether the BioTrans instrument is sufficiently sensitive to detect long term effects of differential treatment in teaching and learning interventions carried out during the students' freshman year and measured during the senior year in dental school. The experimental design for this portion of the study was a repeated measures design, in which each subject acts as his/her own control. Such a design provides increased statistical power over designs of equal sample size with a separate control group.

Learning Interventions

Freshman dental students participate in Module 500, entitled "Introductory Clinical Experiences," which coincides with participation in several of the basic biological science

courses. The purpose of the module is to aid future clinical judgment by presenting learning experiences which help connect biological information with certain clinical procedures. In order to test the effects of overlearning and elaboration on development of cognitive structure (and ultimately on transfer of biological training), clinical tasks and their related biological principles were taught and tested by three different methods as follows.

Forty commonly used dental tasks were selected, four from each of ten clinical disciplines, to provide a core set of clinical tasks and associated biological concepts for the module. The students were provided a syllabus containing all 40 procedural tasks and descriptive narrative about the biological-clinical connections. The students were asked to read about each task and the associated connections, and to view a clinical photograph depicting the procedure. In addition, they were required to observe examples of the tasks being performed during a one hour clinical observation period every other week. They were asked to recall the key biological concepts associated with task decisions while clinically observing the task. Also, the students were asked to think about the dental task each time an associated key biological concept was mentioned in a biological science lecture. This type of learning was labeled "experiential learning."

The forty tasks were assigned in random stratified fashion to four sets containing ten tasks, one from each

clinical discipline. The 1984 freshman class of 76 students was arranged in alphabetical order and assigned alternatively to one of two groups. One set of ten tasks was then randomly assigned to each group. This method had been replicated the previous year with the remaining 20 tasks. The ten tasks assigned were at risk for testing once each month for eight months. For testing, slides were selected at random from those at risk and students were asked to recall the name of the task and four key biological concepts that were part of the information used in decisions made during the performance of the task. The students recalled between 90 and 100 percent of these responses each month, demonstrating overlearning of the tasks and concepts beyond the usual performance requirements. This learning condition was labeled "simple overlearning."

Five of the ten assigned tasks were randomly selected and assigned an additional learning and testing requirement. The students were required to write a short essay about one of the five tasks randomly selected each month. The essays required a description of four decisions that might occur during the performance of the task and an indication of the roles played by the key biological concepts in those decisions. Also, a second paragraph was required describing how the key concepts used in the decisions were related to other biological concepts recently learned in biological science courses. The average student scored above 90 percent on each of these essay tests. This learning condition was

labeled "meaningful overlearning." In summary, each group of students overlearned five tasks with simple associations, five tasks with meaningful associations, and experientially learned 30 other tasks and associated concepts contained in Module 500.

Testing Procedures

Testing for Module 858 took place in April, 1988. At this time, the class size was 65, with changes due to attrition and transfers. All testing took place in the College of Dentistry testing center under equivalent conditions, with no more than 10 students being tested at one time. The testing period took from three to five hours, depending on the working speed of the student. Each student read instructions for the test procedures, then began with the timed WAT testing, followed by five separate patient management problems (PMPs). Work on each PMP was completed and handed in before proceeding to the next. Sequencing of the five PMPs was randomized to avoid a sequencing bias in the test results.

The BioTrans test questions are general in nature, and are applicable to any PMP. For each student, BioTrans tests were randomly assigned to two PMPs. For each such PMP, the student was instructed to complete the PMP first, then proceed to the BioTrans test using the same PMP for the test problem. The random assignment procedures were intended to avoid any systematic biases which could result from sequence of testing, combination of PMPs, or testing fatigue.

Data Collection and Analysis

Each set of test answer sheets was identified by test number only, in order that test results could be scored in a blind fashion. Responses on the BioTrans test were scored blindly by the researcher, identifying only group assignment and test number for each answer sheet. Each of the biological concepts reported were classified into categories of meaningfully overlearned, simply overlearned, or experientially learned. These categories were determined by listing the biological concepts unique to each group of tasks assigned to the student. Scores for both BioTrans tests were summed, then normalized to adjust for differences in the number of concepts at risk in each learning treatment (meaningful overlearning, simple overlearning, experiential learning). Normalizing procedures are described in Appendix D. The data record for each student was thus established, comprised of the number of biological concepts reported in each of three learning categories, plus test identification number.

Each of the three data points in the record represents a correlated or repeated measure for each student. The appropriate statistical analysis to detect differences in the three learning methods for these data was a repeated measures analysis of variance with follow-up comparisons between means of the three measures (Howell, 1982, pp. 363-401). The hypothesis tested in this analysis was the null hypothesis: there were no significant differences in the mean number of

biological concepts, reported on the BioTrans tests, categorized as meaningfully overlearned, simply overlearned, or experientially learned, evaluated at $\alpha = .05$.

Sample Description

Subjects for this study were the 65 senior students of the entering class of 1984 at the University of Florida College of Dentistry (UFCD). There were 19 female students and 46 male students. The entering class was generally representative of the population of public university dental school entering classes with respect to abilities assessed on entrance examinations and pre-professional academic preparation. It is not, however, a random sample from that population. The senior class was representative of recent and near-future senior classes at UFCD. Generalization of results of the experimental and validation portions of this study are restricted to senior dental students who undergo similar training programs in dentistry.

CHAPTER IV RESULTS

Introduction

It will be recalled that the purposes of this study were to present evidence for several types of reliability and validity for the BioTrans test, and to determine its sensitivity to the effects of differential teaching treatments on transfer of biological information to clinical problem solving. The types of reliability and validity investigated were stability, construct validity, and criterion-related forms of concurrent, predictive, and construct validity.

The purpose of presenting evidence of validity is to help this researcher and others decide if the BioTrans test is a useful, meaningful measure for making inferences or decisions based on test scores. As Borg and Gall (1983) have stated, "The prospective test user should ask not 'Is this test valid?' but 'Is this test valid for the purposes to which I wish to put it?'" (p. 275).

The findings of this study will be presented in the following manner. First, findings of test scoring reliability will be presented. Next, results of hypothesis tests for validity and stability will be presented under

headings indicating the type of validity investigated. Following will be the results of hypothesis tests concerning the effects of experimental treatment. Finally, a summary of the findings will conclude the chapter.

Scoring Consistency

The consistency of the researcher in scoring tests was estimated by blindly re-scoring all sets of tests for seven (10.8 percent) randomly selected examinees three weeks after the first scoring. An index of consistency was determined by calculating the percent agreement between scores on the first and second scoring. Ninety percent agreement was obtained.

Tests of Research Hypotheses

Distributions of the data used to test the research hypotheses were examined for normality utilizing stem-leaf plots, box plots, and normal probability plots. The variables of interest were determined to be approximately normally distributed in the sample.

Five research hypotheses were tested to provide evidence of construct validity, stability, and sensitivity to the results of experimental treatment. The first two hypothesis tests will be considered together.

Criterion-Related Construct Validity

Evidence of construct validity was sought by testing correlational hypotheses about the relationships of scores on the BioTrans test, the FJKT, and the WAT. Table 2 depicts the matrix of Pearson product-moment correlations among the

Table 2

Pearson Product-Moment Correlations Among Criterion Test Scores

Test	BioTrans	FJKT	WAT
BioTrans	—	.36*	.16
FJKT		—	.21
WAT			—

* $p < .005$, $N = 61$

three test scores. A significant moderate correlation was found ($p < .05$) between the context-sensitive measures of transfer of biological knowledge (BioTrans) and cognitive structure (FJKT), but no association was found between the BioTrans test and the WAT, a context-free test of cognitive structure.

The first research hypothesis was that the Pearson product-moment correlation coefficient between scores on the BioTrans test and the FJKT is greater than zero, evaluated at a significance level of .05. The results of the study supported this research hypothesis, and indicated that a moderate relationship exists between the two measures (see Table 2), furnishing some evidence for construct validity. The squared correlation coefficient value is .13, meaning that 13 percent of the BioTrans test score variance can be explained by knowledge of scores on the FJKT.

The second research hypothesis was that the Pearson product-moment correlation coefficient between scores on the BioTrans test and the WAT is greater than zero, evaluated at a significance level of .05. The correlation coefficient between these two variables (see Table 2) was not statistically different from zero. The data failed to support the second research hypothesis, indicating that the two tests do not share an association in measuring transfer or potential transfer of biological knowledge.

Predictive Criterion-Related Validity

Predictive criterion-related validity was evaluated by testing the third research hypothesis: The Spearman rank-order correlation between scores on the BioTrans test and final class rank of examinees is greater than zero, evaluated at a significance level of .05. The resulting Spearman correlation was $\rho = -.30$ ($p < .05$, $N = 63$), indicating that a relationship between the two sets of ranks does exist. However, the relationship was inverse and therefore failed to support the research hypothesis.

Stability

The degree of stability of scores on the BioTrans instrument was investigated by testing the fourth research hypothesis: The Pearson product-moment correlation coefficient between scores on the BioTrans test for two separate problems is greater than zero, evaluated at the .05 significance level. The resulting correlation coefficient between BioTrans scores on the first and second patient

management problem testing was $r = .41$ ($p = .0009$, $N = 63$). This result provided moderate support for the fourth research hypothesis.

Experimental Sensitivity and Construct Validity

The fifth hypothesis was tested to determine whether the BioTrans test results demonstrated treatment effects predicted by theory. The null hypothesis of no differences in the mean number of reported biological concepts learned by one of three different methods was tested by repeated measures analysis of variance. Frequency scores of reported biological concepts from each learning method were normalized to adjust for the differences in the number of concepts at risk in each learning method (see Appendix D). The normalized scores were used in the repeated measures ANOVA, and the results are summarized in Tables 3 and 4.

Table 3

Normalized Score Means for Reported Biological Concepts by Learning Method

Learning Method	Mean	<u>SD</u>
Meaningful Overlearning	73.16	25.69
Simple Overlearning	59.45	25.88
Experiential Learning	63.46	30.47

Table 4

Repeated Measures ANOVA Summary--Learning Methods

Source	df	SS	F	ADJ PR > F ^a
Methods	2	5961.45	7.04	.0015*
Error	118	49955.78		

Huynh-Feldt epsilon = .9660

*p < .05

^aProbability adjusted by Huynh-Feldt method for violation of sphericity assumption

The results of the repeated measures ANOVA (Table 4) led to rejection of the null hypothesis of no differences among means. Pairwise post-hoc comparisons of means were performed using Tukey's (HSD) test, as recommended by Stevens (1986, pp. 419-423). The mean number of reported biological concepts from the meaningful overlearning method was greater than the means for either simple overlearning or experiential learning methods ($p < .05$); the means for simple overlearning and experiential learning did not differ significantly.

These results support the alternative hypothesis that the BioTrans test is sensitive for detection of differential transfer of biological concepts resulting from differential treatment during learning. Meaningful overlearning appeared to produce greater transfer of biological concepts to problem solving than simple overlearning or experiential learning. These results provide further evidence of construct validity.

Summary

The results of the data analysis supported three of the five research hypotheses formulated for testing. A significant positive correlation coefficient was found between the BioTrans instrument and the context-sensitive FJKT measure, providing evidence of criterion-related construct validity. A significant positive correlation coefficient was found between BioTrans test scores on the first and second patient management problems using the BioTrans instrument. This finding demonstrated moderate test stability between problems of differing clinical character. Analysis of the effects of experimental treatment furnished support for the construct validity of the BioTrans instrument, and for its sensitivity in detecting such effects. Meaningful overlearning was found to produce greater transfer of biological concepts in the process of clinical problem solving than either simple overlearning or experiential learning. No evidence was found for the particular criterion-related examinations of concurrent validity or predictive validity. Discussions of the findings, their implications, and suggestions for further research are presented in Chapter V.

CHAPTER V DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Discussion

Review of the relevant literature indicated the need for development of valid, reliable measures of clinical performance which reflect current theories in the areas of transfer of training and clinical problem solving. The present investigation was designed to develop one such measure, the BioTrans test. In addition, the investigation was expected to answer questions focused on test reliability, validity, and sensitivity. Correlational hypotheses were tested to determine whether test score data provided evidence of stability, criterion-related construct validity, concurrent criterion-related validity, and predictive criterion-related validity. A hypothesis concerning expected effects of differential teaching methods was tested to determine experimental construct validity and test sensitivity. Each section of the discussion will center on the results of one of these reliability or validity tests.

Criterion-Related Construct Validity

Results of the data analysis indicated that evidence for construct validity was found by virtue of the positive significant correlation coefficient between scores on the BioTrans instrument and scores on the FJKT. The coefficient

was $r = .36$, and was interpreted as a moderate correlation providing modest evidence for construct validity.

Understanding the moderate correlation finding can be aided by reviewing the method of administration of the two tests under consideration. The BioTrans test relies on a specific patient management problem for preparation in responding to problem-solving questions posed in the test. The cues, which may trigger access pathways to relevant concepts in the student's memory, are specifically provided by the problem. Thus, the BioTrans test measures cued recall.

In contrast, on the FJKT the student is asked to recall a clinical incident in which biological knowledge made a difference in treatment. In this situation the student is, in effect, providing a personal patient management problem, including the access cues. The availability of information stimulated by the FJKT is dependent upon free recall instead of problem-cued recall. In addition, students tended to report incidents which were narrow in scope, and probably stimulated fewer cue pathways than the patient management problem. The existing commonalities between the results of the two tests under consideration, therefore, are likely the expression of similarities in cognitive structure and a general similarity of context. The context is that of clinical patient problems and recognition of the utility of biological knowledge for problem solving.

The BioTrans test and the FJKT may be viewed as instruments measuring related constructs which have a common basis of organization of biological knowledge. Thus, it would not be expected that a high correlation coefficient would result from this data analysis.

Concurrent Criterion-Related Validity

No evidence was provided for concurrent validity, as hypothesized, by the relationship between the WAT and the BioTrans test results. This unexpected result may have occurred because the context-free single task or single concept cues used to stimulate recall did not overlap appreciably with those found in the patient management problems. If so, limited overlap could produce responses which represent different segments of cognitive structure, leading to a lack of relationship between the test results. This finding may be an expression of fundamental differences in the information structures which are recalled by context-rich or context-free methods of stimulation. The WAT and the BioTrans test differ in the context provided to cue recall. The WAT is essentially context-free, relying on a single word or phrase as the cue. In comparison, the BioTrans test problem is rich in clinical problem context, generating a wealth of cues in the problem description. These context differences and their results may account for the lack of association of scores on the two tests.

Finally, it may be that there is a modest relationship between the two measures, but that the method of scoring, the

size of the sample, or restriction in range of variability do not allow detection of that relationship. The guidelines used for categorizing and counting types of concepts may be insufficiently precise to detect subtle relationships.

Predictive Criterion-Related Validity

An unexpected finding occurred in the examination of the relationship between BioTrans score ranks and the final class ranks. A significant, small negative rank correlation ($-.30$) was found, indicating that the two ranks are inversely related. This means that high BioTrans score ranks are slightly predictive of low final class rank.

This unanticipated finding could be due to an assumption made about the nature of the final class rank. It was reasoned that the final class rank emphasized clinical performance because the senior year is dominated by clinical course work and clinical practice. It may be, however, that senior year evaluations reflect performance in technical excellence and procedural knowledge more than performance in clinical problem solving or level of biological knowledge. Stated differently, it appears that clinical instructors tend to evaluate technique and attention to detail, rather than diagnostic problem solving, treatment planning, or application of biological knowledge. If this is true, then the researcher might search for other measures of biological knowledge of predictive interest to look for a positive, predictive relationship.

Stability

The hypothesis concerning stability of BioTrans scores from one testing to the next was evaluated by investigating the correlational relationship between first and second problem test scores. A significant positive moderate correlation was found ($r = .41$) furnishing support for the stability hypothesis. This finding is encouraging in view of the fact that first and second testing is accomplished using different patient problems. It was reasoned that the tests, though different in clinical presentation, would draw upon similar cognitive structures of biological concepts for problem solution. The attained stability coefficient substantiates that reasoning.

The lack of a high correlation between different problems is similar to findings of other studies which investigated transfer of the medical problem-solving process among different clinical problems. For example, low correlations between performance scores on unlike medical problems were found by Elstein, Shulman, and Sprafka (1978), prompting conclusions about lack of transfer of problem-solving skills. Norman and co-workers (1985) reviewed similar reports and inferred that performance variability on single problems measured by existing methods was too great to determine lack of skill transfer. McGuire (1985) also criticized the narrow methodologies and broad conclusions of such studies.

A finding of moderate test stability can result from a combination of influences. First, the likelihood of wide variability on single problem scores lessens the probability of a high stability coefficient. Second, an opposing influence, the transfer of biological knowledge during the solution of different problems, would increase the probability of at least a moderate coefficient. Few conclusions can be drawn about the effectiveness of transfer of problem-solving skills on the basis of data derived from only two problems.

Experimental Construct Validity and Sensitivity

The finding of a significant difference in the mean number of biological concepts reported from three different learning methods provides the strongest evidence for construct validity. The BioTrans test results demonstrated, in part, differences in recall predicted by theory. Meaningfully learned concepts were expected to be reported most frequently; the data supported this prediction.

Simply overlearned concepts were expected to be reported more frequently than experientially learned concepts. This difference was not demonstrated by the data. It is possible that these two methods do not produce striking differences in availability of knowledge. For example, much of the experiential learning may have involved rote memorization for purposes of multiple choice testing, with little or no clinical context. In the case of simple overlearning, students' freshman quiz scores demonstrated that overlearning

did take place. However, the simple overlearning may have been, essentially, practiced rote memorization of only a few of the concepts at risk, because students were required only to identify a procedure and list four associated biological concepts for the monthly quizzes. Context during learning was available in the narrative description of the syllabus. But understanding was not required, as it was in meaningful overlearning. Therefore, cognitive structure developed by simple overlearning or by experiential learning may be equivalent when tested by the BioTrans instrument. It also may be that the instrument can not detect small, true differences of this nature with a sample of 60 examinees.

Conclusions and Recommendations

Based on the results of this study, several conclusions may be drawn about the BioTrans test instrument and the experimental results obtained by its use. First, evidence of construct validity has been provided by the association shown with a context-sensitive measure of cognitive structure, and by the detection of effects of experimental treatment predicted by theory. Second, test stability has been demonstrated by the correlation of test scores using two separate patient management problems. Third, the BioTrans test data do not indicate evidence of predictive validity for final class rank, nor evidence for similarity to biological knowledge organization elicited by the WAT, a context-free measure.

Fourth, meaningful overlearning produces greater transfer of biological concepts to the process of clinical problem solving, using patient management problems, than either simple overlearning or experiential learning. Fifth, simple overlearning and experiential learning do not appear to differ in the amount of transfer of biological knowledge produced during patient management problem solving. Therefore, other investigators should find the BioTrans test useful as a valid, reliable instrument for evaluating student performance or program effectiveness.

This experience with the BioTrans instrument draws attention to some recommended changes in methodology which would strengthen the utility of the test for understanding the effects of learning methods on transfer of knowledge. The patient management problems used in the present study were chosen from among those already in use for the curricular module for evaluating clinical judgment. These problems were collected or formulated to test the most important diagnosis and treatment decisions commonly encountered in each dental discipline. Presently, there is inadequate integration of disciplines in these problems. Therefore it would be preferable if patient management problems were developed specifically for use with the BioTrans test. The new problems should require consideration or application of those particular clinical tasks studied in the freshman learning module.

Once the desired management problems were developed, equivalent forms could be prepared. A better estimate of stability of test scores under equivalent forms then would be possible. Preparation of appropriate management problems is extremely time consuming, and heretofore has not been done with these purposes in mind.

It would be instructive to rescore and analyze the WAT and FJKT responses to reflect the frequencies of concepts learned by each method. A repeated measures ANOVA could then be performed to determine if either of these tests demonstrate the same effects of differential treatment in learning shown by the BioTrans data. These results may shed new light on the hypothesized differences in transfer of simply overlearned and experientially learned concepts.

It is recognized that collecting, training, scoring, and analyzing data with the BioTrans test instrument is quite time consuming. The test will be of less utility to the dental educator who needs easily scored data for making rapid decisions for student evaluation. The BioTrans test will be of greater interest to the dental educational researcher who wishes to gain understanding of subtle long-range consequences of a teaching program and its effects on transfer of learning. With slight modification, the BioTrans test may prove useful in continuing education programs for evaluating the transfer of recently learned clinical concepts, particularly if forms of overlearning have been used in the training sessions.

APPENDIX A
TEST OF TRANSFER OF BIOLOGICAL KNOWLEDGE

Please Read These Instructions Carefully

It is widely recognized in dentistry that basic biological sciences provide the foundation for understanding and solving clinical problems. In the early portion of your dental training you acquired a knowledge base in biological sciences, which was reinforced and related to clinical practice in Module 500 (Introductory Clinical Experiences). You have extended that knowledge in your clinical training and clinical experience. Draw upon that knowledge while responding to the questions and statements of this test.

This test is designed to measure your ability to transfer basic biological knowledge to solving clinical problems in dentistry. You will be asked to identify basic biological knowledge related to each step as you proceed through a clinical problem-solving format. Basic biological knowledge consists of the concepts and relationships which you learned in your course work in anatomy, embryology, biochemistry, microbiology, histology, physiology, pathology, pharmacology, and neurosciences. Many of these concepts were reinforced and elaborated in a clinical context during Module 500.

You will be scored on the number of truly applicable biological concepts (both applied and basic) that you relate

to each question. Biological concepts can be quite specific (e.g. osteoblasts, synaptic transmission) or somewhat broad (e.g. skeletal malocclusion). Examples of clinical cues (signs and symptoms), diagnosis, and some related biological concepts are given below for a particular orthodontic case. The example responses are by no means exhaustive, but are provided to guide you in the types of responses expected.

Clinical Cues: Patient appearance, chief complaint, examination of occlusion, radiographic examination

Diagnosis: Mandibular prognathism

Related Biological Concepts:

Applied -- Orthodontic treatment forces, skeletal malocclusion, impaired mastication

Basic -- Growth centers, growth direction, endochondral bone, intramembranous bone, sutures, age, genetic determinants, nutrition, mineralization, osteoblast activity

Your thoughtful responses to this test will provide a measure of your ability to apply biological principles to your performance in clinical thinking and judgment. The following questions apply only to the patient care problem (case) that you have just completed. Please answer each question as completely and specifically as you can. Do not limit your answers to broad concepts only; include related detailed concepts from as many basic science disciplines as you can. Remember, the more concepts from as many of the

basic science disciplines (listed again below) that you relate to your case, the better your score. If necessary, use the back of the answer sheet to complete your answer.

Anatomy

Embryology

Biochemistry

Microbiology

Histology

Physiology

Pathology

Pharmacology

Neurosciences

Examinee Number _____
Date _____

Test Number _____
Start time _____
Stop time _____

I. A. State the cues (signs and symptoms) that led you to identify the one most important clinical problem in this case.

B. What are the biological concepts associated with the cues (signs and symptoms) that relate to this problem for the patient?

C. You may have identified additional clinical problems in this case. If so, what cues (signs and symptoms) led you to identify these problems?

D. List the biological concepts associated with the cues (signs and symptoms) that relate to these additional problems for the patient.

Examinee Number _____
Date _____

Test Number _____

II. A. In reviewing the data (history, examination, laboratory findings, models, radiographs) you formed a primary diagnosis with possible secondary diagnoses. Write down your primary and secondary diagnoses.

B. For each diagnosis, list the biological concepts that you believe characterize or distinguish the diagnosis, other than those already listed in section I.B. (By making a formal diagnosis, you will be likely to recall concepts not yet considered.)

C. Upon hearing your explanation of the diagnoses, the patient indicates lack of interest in continuing with any treatment. What biological concepts might be used in explaining to the patient the consequences of no further treatment?

Examinee Number _____
Date _____

Test Number _____

III. A. Your final goal in the case was to formulate a plan for therapy and management of the patient. Briefly summarize your therapeutic management plan.

B. During therapy, events may occur (e.g. enamel fracture, drug reaction, soft tissue changes) that require altering the treatment plan. Identify one such potential event in your case, and indicate the biological concepts related to this event.

C. After completion of treatment, what cues (signs and symptoms) would you wish to monitor in order to evaluate short-term and long-term outcomes of treatment? What biological concepts are associated with the items to be monitored?

APPENDIX B
DECISION RULES FOR COUNTING BIOLOGICAL CONCEPTS
(Adapted from Mackenzie et al., 1986)

What is a biological concept? It is an idea that is basic to the biological sciences, in this case usually pertaining to structure and/or function of the human organism. The concepts can be single or compound. When the meaning of a concept is modified by additional words it is considered a compound concept. A single concept and a compound concept derived from this single concept are counted independently. The modifier words that form a new compound concept are not counted independently, but are considered part of the newly formed idea.

Ideas counted as one biological concept may be single or compound:

Single Nouns: heart, tooth, diabetes, TMJ, inflammation, growth, trauma, infection, pain.

Compound concepts which are counted as only one concept may be composed of various elements:

Adjective(s) + noun: harmful lesion, exposed pulp, gingival tissue, infected tissue, debilitating condition, etc. (e.g. exposed pulp is counted as a different concept than necrotic pulp).

Noun phrases are considered a compound concept, for examples: prevention of heart problems; decreased mobility of teeth; sensitivity of tissue; capacity to handle stress; ability to produce dentin; resorption of bone; gingival retraction.

Exception: noun phrases tying together several distinct biological concepts will count all those concepts separately, for examples: osteoclastic activity (1) of bone (2); white cell invasion (1) of gingival tissue (2). Note that gingival tissue is counted as one concept, whereas tissue of the gingiva would be counted as two.

Verb phrases are considered a compound concept: I considered "the chance of staphylococcal infection."

Exception: same as noun phrases (e.g. verb phrases tying together several distinct biological concepts).

Verb--to be--(conjugated in any tense, but not as an auxiliary verb, as in the passive voice of another verb) connecting noun and adjective or participle: tissues were in a degenerated state (e.g. degenerated tissues). Patient has been terminally ill (e.g. a terminally ill patient).

Biological concepts can be considered compound when they are formed by two or more nouns connected by prepositions. A compound concept occurs when a preposition connects one biological concept to another non-biological noun which helps clarify its meaning or adds a distinctive attribute to this biological concept; then the compound concept is counted as one. E.g., blood supply to the area; detrimental to health; material in the canal; knowledge of anatomy; Bell's palsy on the right side; etc. However, when prepositions connect independent biological concepts, the biological concepts are counted independently. For instance, anesthetic with epinephrine, growth on the tongue, white lesion on the palate, muscles of the tongue.

Exceptions: commonly used biological concepts that have come to stand for one idea; e.g. muscles of mastication.

When we have a verb that signifies a biological concept, we perform a transformation called nominalization. The nominalized concept is then counted for classification purposes. E.G., patient survived the crisis == patient's survival of the crisis; to relieve pain == pain relief; gingival tissue receded == recession of gingival tissue; the condition that patient presented == patient's condition (note that this example has a relative pronoun, "that." When allowed by the meaning of the sentence-phrase, transformations involving relative pronouns are permissible).

When biological concepts are connected by a conjunction (i.e., and, or), they should be counted as separate. E.g., physical and mental health == physical health and mental health.

Rules for counting biological concepts.

1. Count the same concept only once, if repeated within the same test (including plurals of single nouns). However, count paraphrases of the same concept as if they were different concepts (e.g., hemorrhage-bleeding; gingivitis-gingival inflammation). Count tooth only once in same test regardless of the number of paraphrases (e.g., tooth, molar, incisor, abutment, #20).

2. If concept's meaning is changed by compounding, then the concept is counted independently each time the meaning is changed in a different way within the test (e.g., dental caries and rampant caries; the beginning of an inflammatory process, or the resolution of the same process will be counted as different concepts). Whenever two compound concepts have the same root word but different meaning, count them as separate concepts (e.g., carious lesion, carious exposure).

3. When the response is furnished with biological concepts that are examples of the main biological concept, count each example separately (e.g., periodontal disease such as gingivitis, periodontitis). The same rule applies when additional information to the main biological concept is given (e.g., rheumatic fever [heart valve damage]). However, examples of biological concepts that are not biological are not included, e.g., irritant factor such as cold. Cold is not a biological concept.

APPENDIX C
VALIDATION INSTRUMENTS

Functional Job Knowledge Test

Student Name _____ Patient's Name _____

Date ____ Approximate Date Service Rendered _____

Test of Applied Knowledge

As directed in the instructions, think of a specific clinical situation in which biological knowledge made a difference in providing a better service. Be specific:

1. What were the circumstances leading up to the incident (including service being rendered)?

2. What did you notice (see, hear, feel) that indicated the need to use biological information?

3. What did you do or say based on the biological information, that contributed to the quality of the service rendered?

4. What was the biological information (fact or principle) that made a difference in what you did or said?

5. How did this information help provide better service (e.g., potential consequences avoided and/or the positive benefits of applying the information)?

WORD ASSOCIATION TEST

This is a test to see how many words you can think of and write down in a short time.

You will be given a key word which represents a concept in "biology" or a task in clinical dentistry and you are to write down as many other words which the key word brings to mind as you can.

Write as many words as you can which the key word brings to mind. You will probably not be able to fill in all of the spaces on a page, but do the best you can. Be sure to think of the key word after each word you write down, because the test is to see how many other words the key word makes you think of.

For example, suppose I asked an electrician to write down as many words relating to electricity (his specialty) as he could think of when given the word "Conductor." He might put down the following:

Conductor

Conductor metal
 Conductor charge
 Conductor transmit

Conductor resistor
 Conductor _____
 Conductor _____

You will notice that as an electrician, he did not put "train" or "cable car" or "guide," since they do not relate to the electrical concept of "conductor." In this same way, you should think like a dentist based on what you have learned in dental school when you respond to the concepts.

You will have one minute on each page. I will tell you when time is up and give you the next sheet.

This test, in conjunction with different tests given to other students, is important for evaluating the impact of the curriculum on clinical thought processes. The evaluation is part of our continuing self study to help us improve instruction. This test replaces a test, and is not in addition to the other tests you would ordinarily take.

To pass this test you need only make a valid attempt to help us improve.

The examination proctor will administer the test to you.

APPENDIX D
NORMALIZING PROCEDURES FOR BIOTRANS TEST SCORES

A weight for each type of learning score was derived by expressing the number of concepts at risk in each learning category as a proportion of the total number of concepts at risk, then calculating the inverse of that proportion to obtain the weight. The product of the weight and each corresponding raw score produced the normalized score. For example, if the number of meaningfully overlearned concepts at risk were 84, and the total number of concepts at risk were 401, then the proportion equals $84/401 = .21$, and the inverse is $1/.21 = 4.76$, the derived weight. This weight was multiplied by each meaningfully overlearned raw score to obtain a normalized meaningfully overlearned score. The following weights were utilized in this study.

- | | | |
|-----------------|--------------------------|------|
| 1. Odd group - | Meaningfully overlearned | 4.76 |
| | Simply overlearned | 5.00 |
| | Experientially learned | 1.70 |
| 2. Even group - | Meaningfully overlearned | 3.45 |
| | Simply overlearned | 5.26 |
| | Experientially learned | 1.89 |

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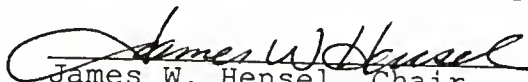
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BIOGRAPHICAL SKETCH

Robert Edwin Martin was born in Denver, Colorado, on November 12, 1937. He attended public schools there, graduating from East High School in 1956. Having been awarded an NROTC Regular Scholarship, he attended the University of Missouri, Columbia, graduating with a Bachelor of Science degree in physics and receiving a commission as Ensign, U.S. Navy in 1960. During three years of active duty with the Navy, he served on destroyers in the Western and Eastern Pacific, receiving promotions to Weapons Department Head and Navigator.

In 1964, Mr. Martin was accepted in the School of Dentistry, University of Washington, Seattle, where he graduated in 1968 with the degree of Doctor of Dental Surgery. He subsequently practiced general dentistry in the Seattle area for several years. In 1985, Dr. Martin began preparation for a role in academic dentistry by entering the Ph.D. program in higher education administration at the University of Florida, with emphasis in dental science and education. During his graduate studies he has served as a graduate research assistant in dental education, authored a clinical research training manual and syllabus for use in the National Curriculum for Dental Educators, and taught a course in multivariate clinical research design to dental faculty.

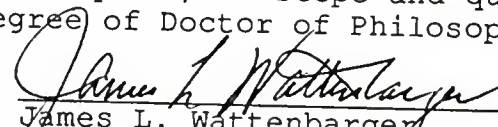
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James W. Hensel, Chair
Professor of Educational Leadership

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

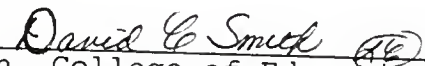

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